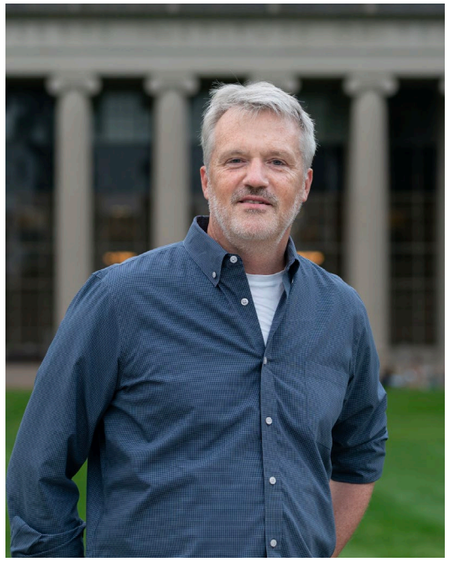
An Introduction to Robot Autonomy

with

MOOS-IvP

and

Aquaticus



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Lecture 4.5: Project Aquaticus Mechanics and Integration

Prof. Michael “Misha” Novitzky
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MOOS-IvP Supported by ONR Code 311 since 2000

Aquaticus Supported by ONR, DARPA, Battelle and the Army Research Lab

MOOS-IvP and Aquaticus

MOOS-IvP

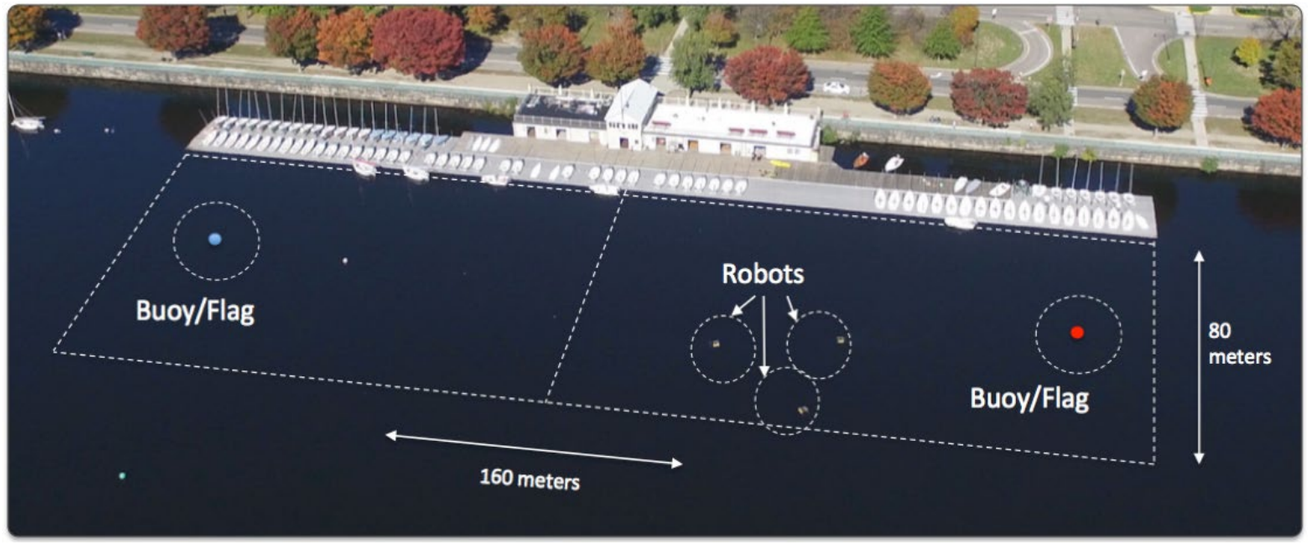
www.moos-ivp.org

- MOOS robot middleware
- IvP Autonomy architecture
- Open source since 2006
- On dozens of platform types around the world

Aquaticus

www.aquaticus.org

- An adversarial competition
- Based on capture-the-flag
- Played on the water
- Software infrastructure MOOS-IvP
- Started at MIT, now at West Point.



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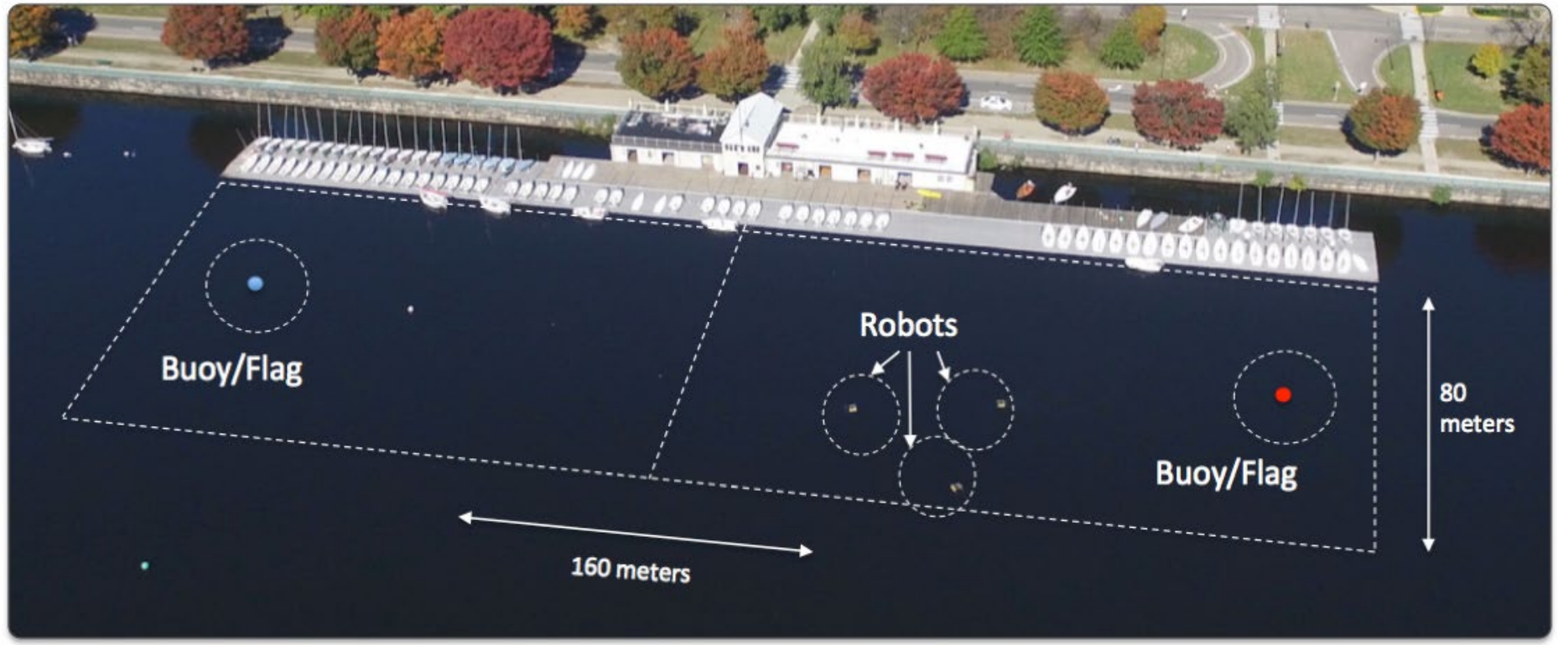
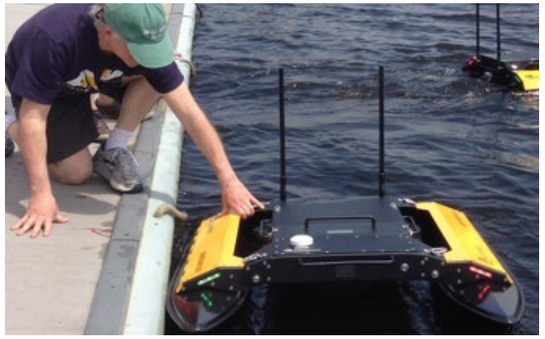
Aquaticus Human-Robot Cooperative Teaming Test-bed

Dr. Michael Benjamin, Dr. Michael Novitzky, Prof. Henrik Schmidt





- Mixed Human-robot teaming with humans in field with robot teammates.
- Unique factor: full in-field integration of human teammates. Multiple communication modes.
- Field is ~160x80m on Charles River at MIT.
- Choice of robot autonomy configurations, modes, strategies, contingencies, protocols must consider what is most useful and digestible to humans
- Humans are in motorized kayaks with voice-to-text for comms to robots.

- Funded by DARPA TTO through ONR. Seedling. ARL-STRONG
- Full competitions (4 on 4) during summer 2018.
- Operated in conjunction with Marine Autonomy Summer High School Program (Year 3, 2018)
- Human-Use Approval (MIT, DoD) March 2017.
- Goals, operating environment, team structure may be changed mid-competition, per requests of model developers.

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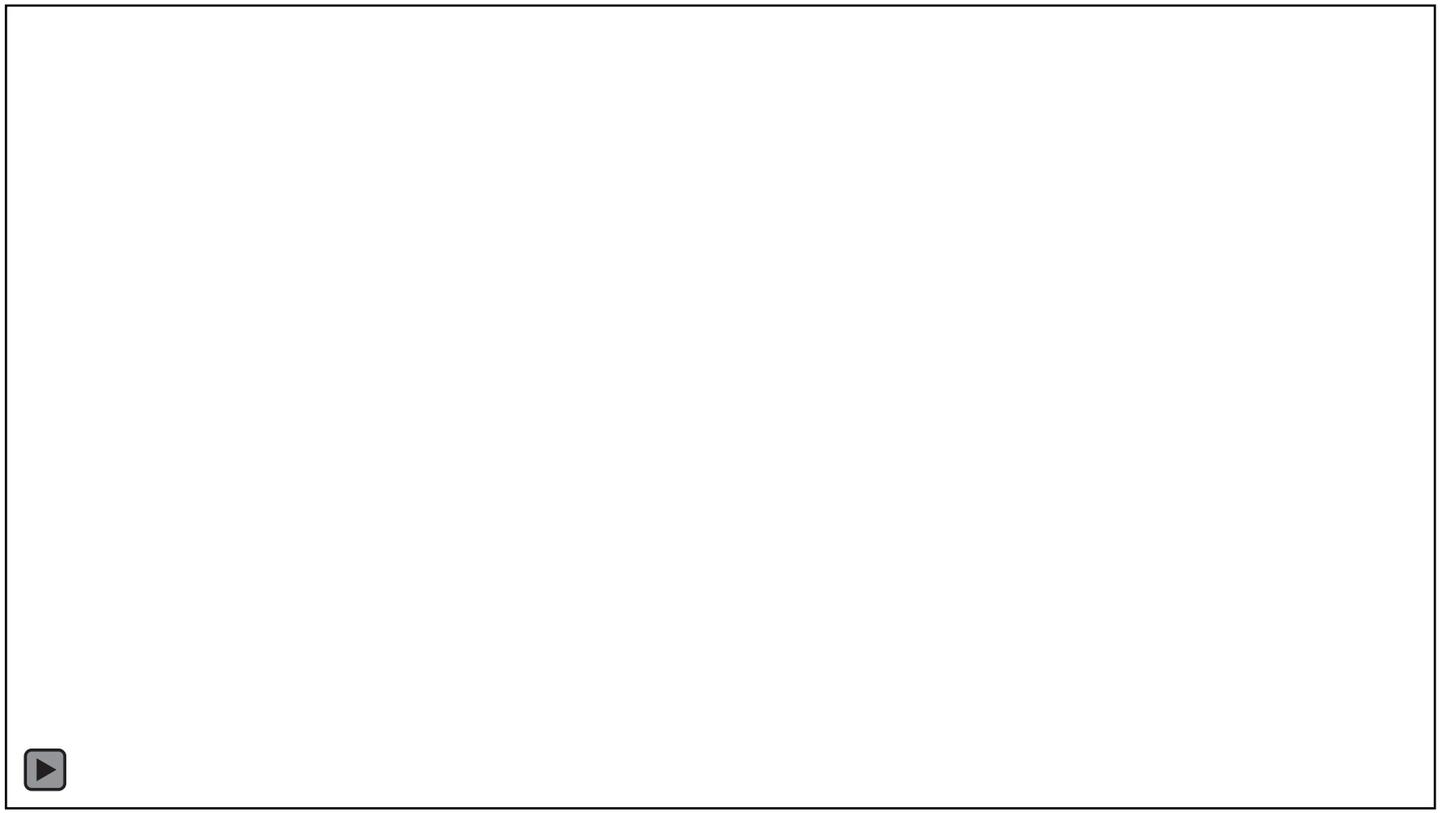

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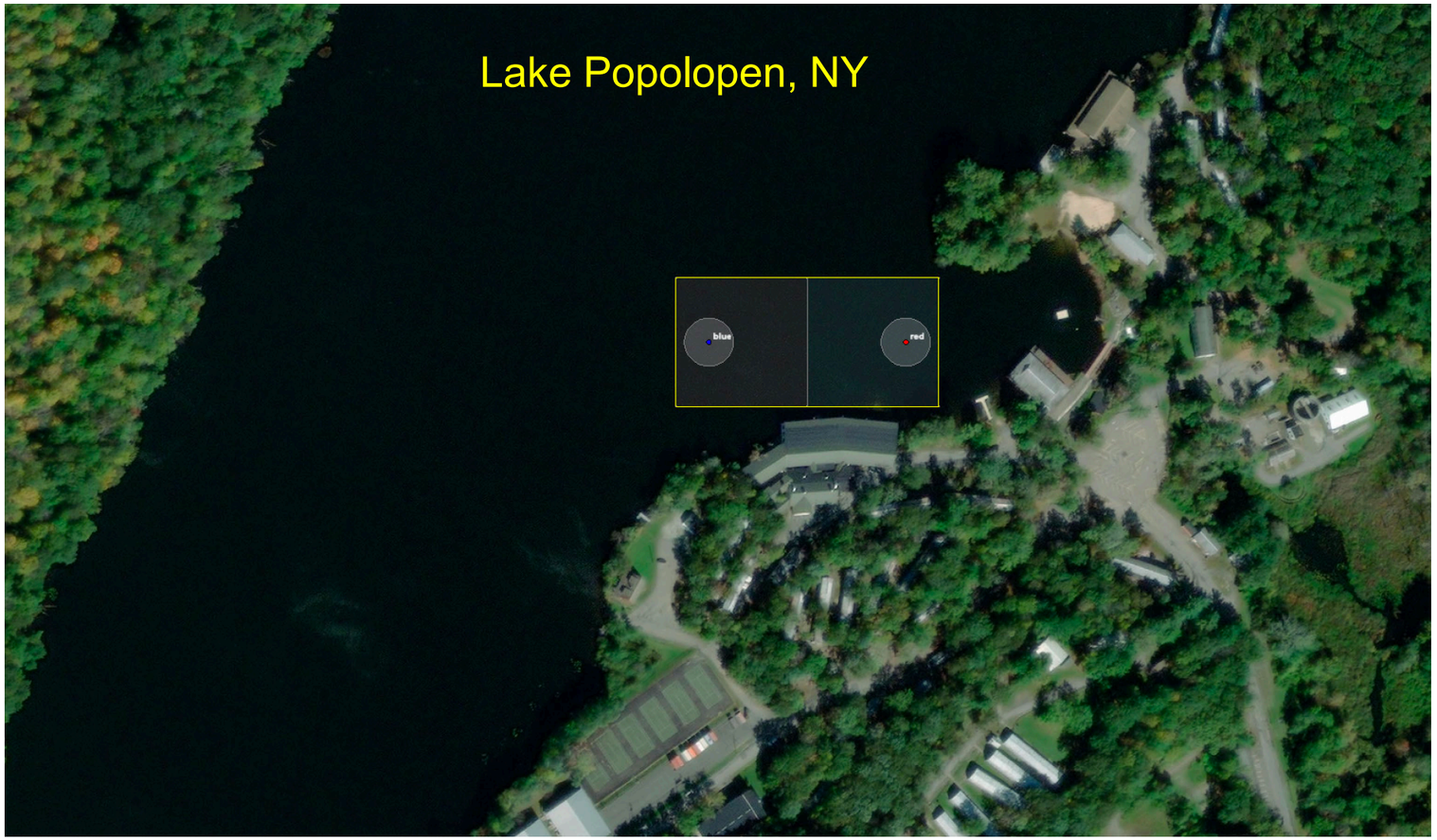
Moved to West Point NY

- Flags are anchored buoys
- ”capturing” of flags is virtual. Must be within flag zone.
- Field boundaries are virtual with penalties for going out of bounds



Location:
Lake Popolopen, NY

Dimensions:
160x80m

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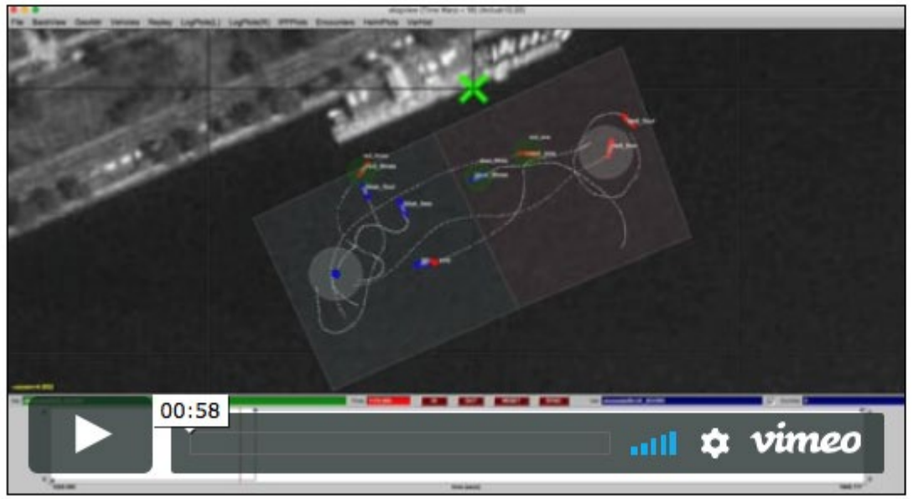
Winning Tactics

- Naval Postgraduate School
- Roles
- Time
- Listened to comms



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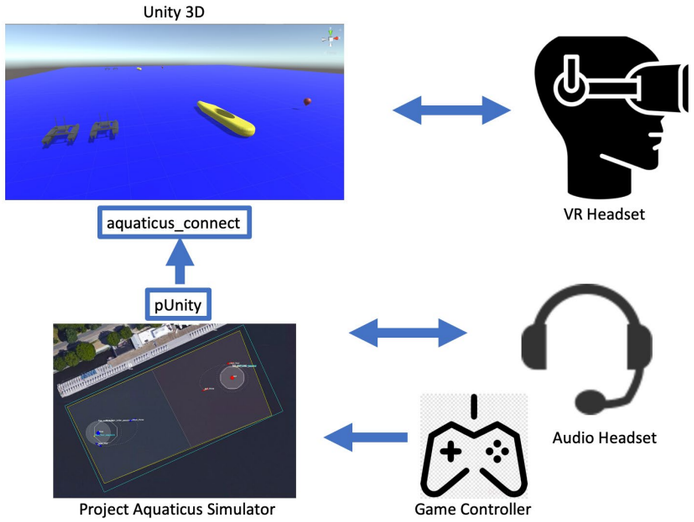
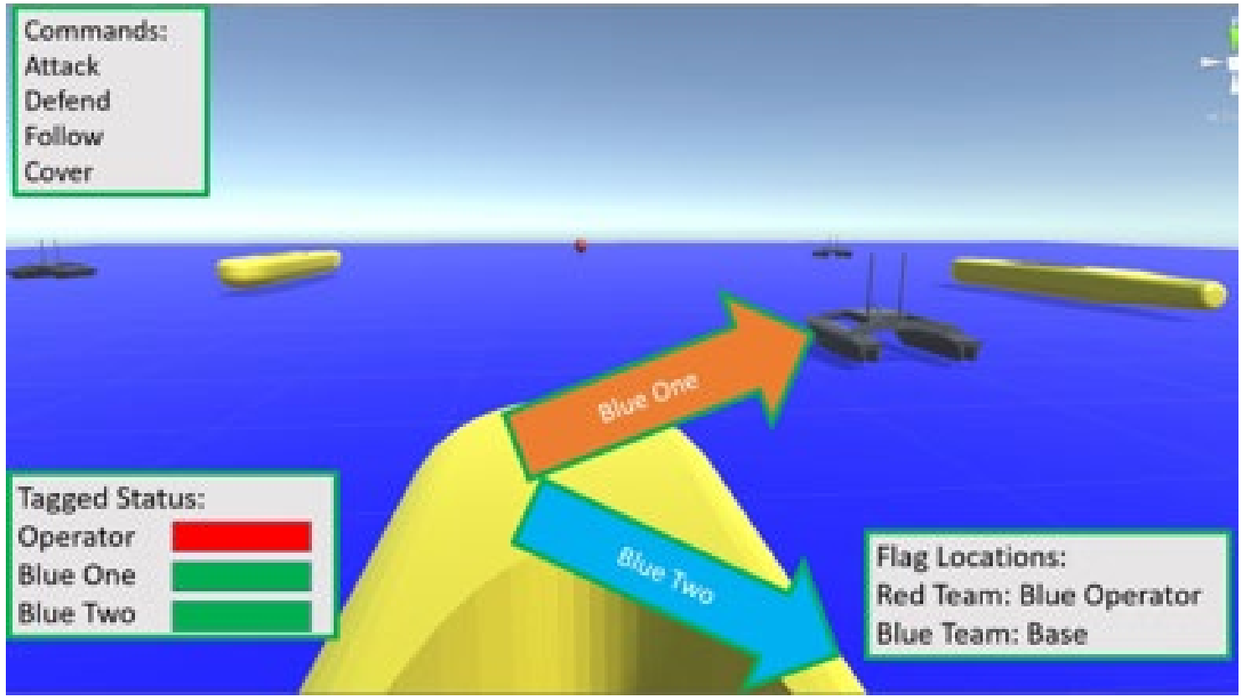
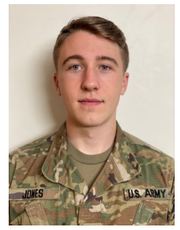
Virtual/Augmented Reality





Green is Augmented Reality

Independent Study



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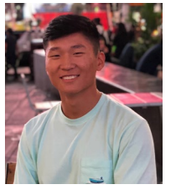
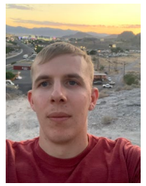
pLearn

- Fitted Q Learning
- TensorFlow/Keras
- Scripts for learning

Independent Study and Honor Thesis





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Aquaticus Mechanics

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Aquaticus Playing Field

Competition based on Capture the Flag

- Flags are anchored buoys
- ”capturing” of flags is virtual. Must be within flag zone.
- Field boundaries are virtual with penalties for going out of bounds
- Defend with “tags”

Location:
Charles River at MIT

Dimensions:
160x80m

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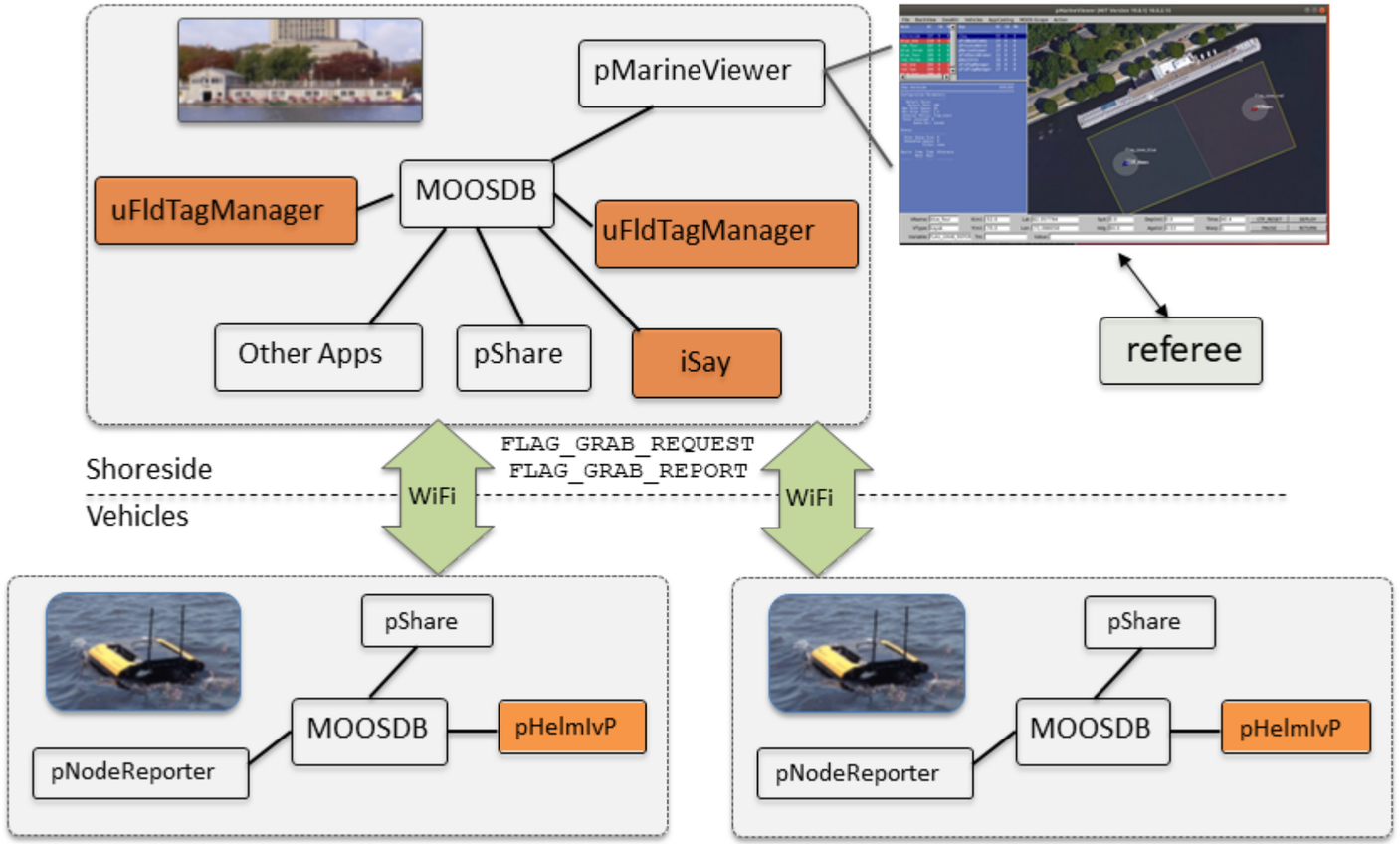
Aquaticus Playing Field

Competition based on Capture the Flag

- Share locations
  - Collision Avoidance
  - Game mechanics
- Requests
- Announcements



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Aquaticus Autonomy

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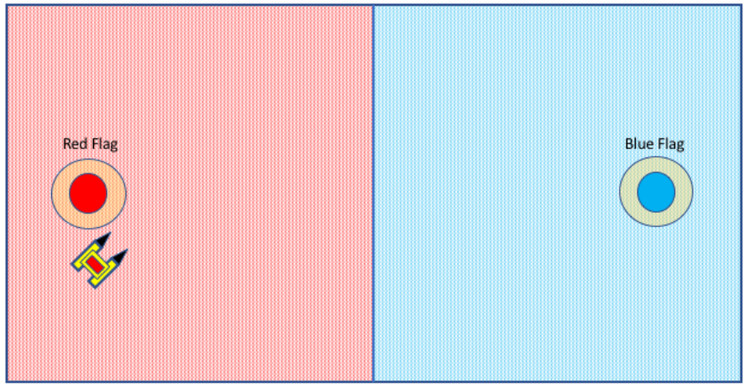
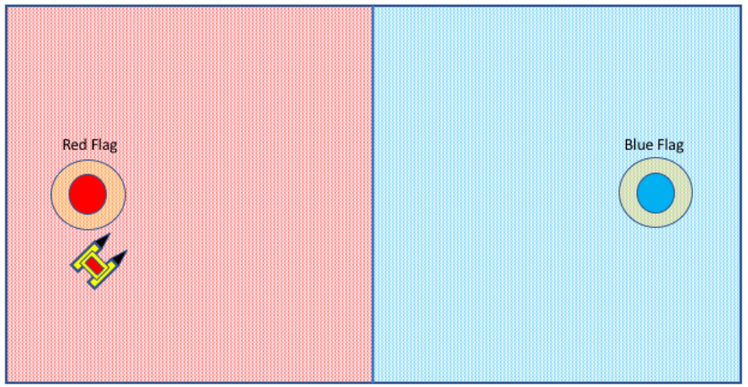
Aquaticus Playing Field

Individual

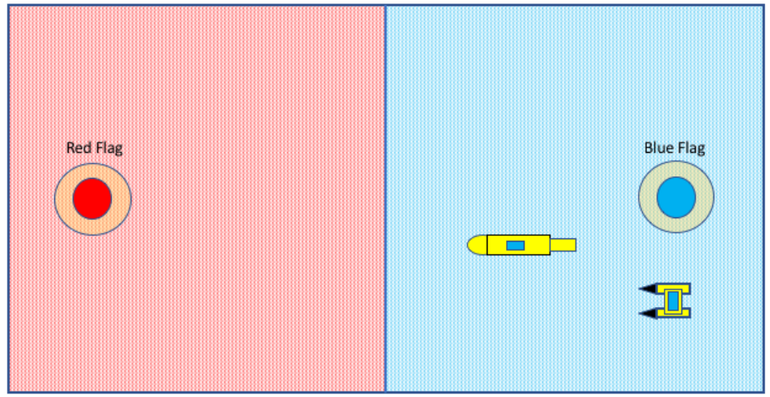


Defend

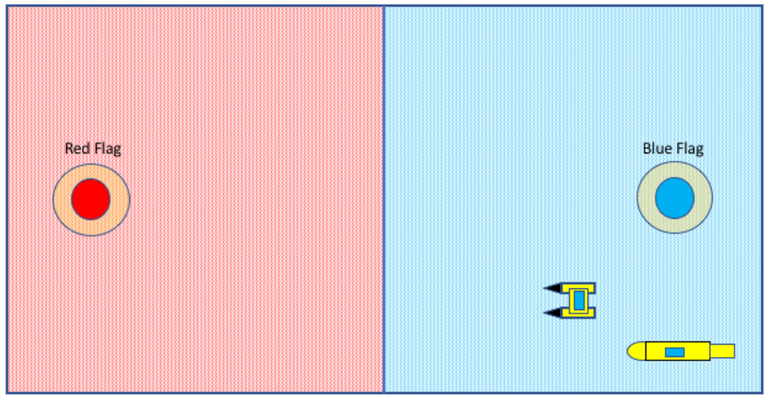


Attack

Teamwork



Trail



Cover

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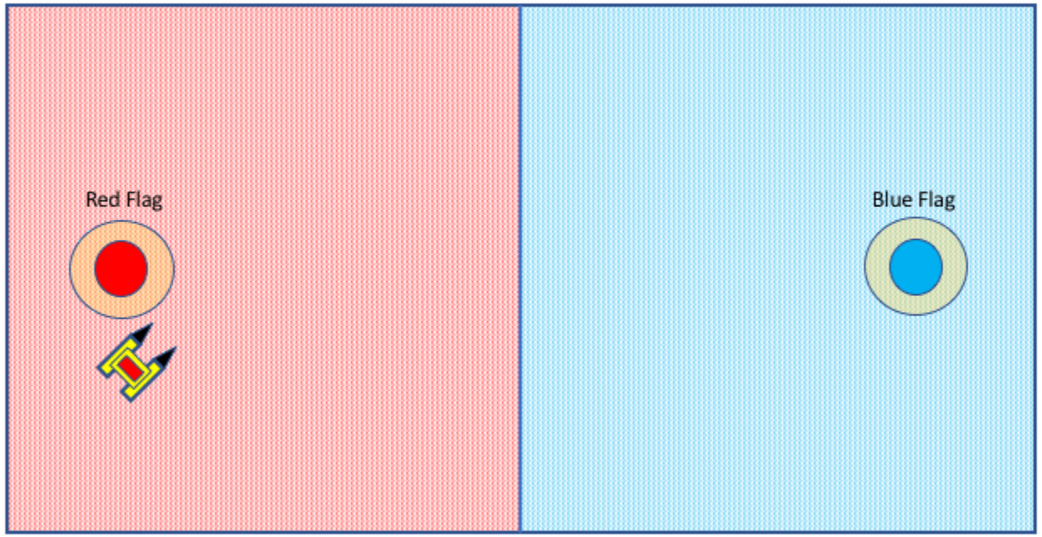
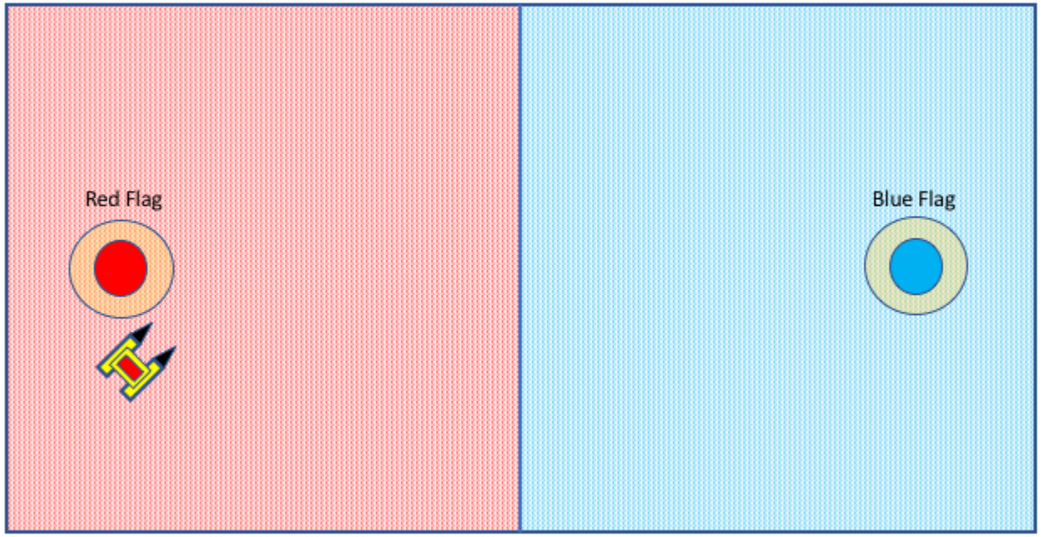
Aquaticus Playing Field



Attack Right



Attack Left

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Aquaticus Helm Hierarchy Tree

uHelmScope

```
Mode-Variable=MODE
ACTIVE
   RECOVERING
   RETURNING
   INGAME
      SOLOPLAY
         ATTACKING
            TAGGED
            UNTAGGED
               AVOIDING
         ATTACKING_LEFT
            TAGGED
            UNTAGGED
         ATTACKING_RIGHT
            TAGGED
            UNTAGGED
         DEFENDING
            PASSIVE
            PROTECTING
      TEAMPLAY
         TRAILING
         COVERING
         SHIELDING
         STATIONING
INACTIVE
```

meta_heron.bhv

```
initialize DEPLOY     = false
initialize RETURN     = false
initialize ACTION     = $(START_ACTION)
initialize TAGGED     = false
initialize AGGRESSIVE = false
initialize RECOVER    = false

set MODE     = ACTIVE {
  DEPLOY     = true
} INACTIVE

set MODE     = RETURNING {
  MODE       = ACTIVE
  RETURN     = true
} INGAME

set MODE     = SOLOPLAY {
  MODE       = ACTIVE:INGAME
  (((ACTION    = ATTACK) or ((ACTION = ATTACK_LEFT) or (ACTION = ATTACK_RIGHT))) or ((ACTION = INTERCEPT) or (ACTION = DEFEND))) or (ACTION = PROTECT)
}

set MODE     = TEAMPLAY {
  MODE       = ACTIVE:INGAME
  ((ACTION    = COVER) or ((ACTION = STATION) or (ACTION = TRAIL))) or (ACTION = SHIELD)
}

set MODE     = ATTACKING {
  MODE       = ACTIVE:INGAME:SOLOPLAY
  ACTION     = ATTACK
}

set MODE     = DEFENDING {
  MODE       = ACTIVE:INGAME:SOLOPLAY
}

set MODE     = TAGGED {
  MODE       = ACTIVE:INGAME:SOLOPLAY:ATTACKING
  TAGGED     = true
} UNTAGGED

set MODE     = TRAILING {
  MODE       = ACTIVE:INGAME:TEAMPLAY
  ACTION     = TRAIL
}
```


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Aquaticus Helm Hierarchy Tree

uHelmScope

```
Mode-Variable=MODE
ACTIVE
   RECOVERING
   RETURNING
   INGAME
      SOLOPLAY
         ATTACKING
            TAGGED
            UNTAGGED
               AVOIDING
         ATTACKING_LEFT
            TAGGED
            UNTAGGED
         ATTACKING_RIGHT
            TAGGED
            UNTAGGED
         DEFENDING
            PASSIVE
            PROTECTING
      TEAMPLAY
         TRAILING
         COVERING
         SHIELDING
         STATIONING
INACTIVE
```

meta_heron.bhv

```
//Behavior = BHV_AvoidCollision
 {
   // General Behavior Parameters
   // ----------------------------
   name         = avdcollision_
   pwt          = 300
   updates      = CONTACT_INFO
  endflag = CONTACT_RESOLVED = $[CONTACT]
   templating   = spawn


   // General Contact Behavior Parameters
   // ------------------------------------
      bearing_lines = white:0, green:0.65, yellow:0.8, red:1.0   // example

            contact = optional_vehicle_name
              decay = 15,30
          extrapolate = true
    on_no_contact_ok = true


   // Parameters specific to this behavior
   // ------------------------------------
     completed_dist = 15
   max_util_cpa_dist = 10
   min_util_cpa_dist = 5
          pwt_grade = linear
     pwt_inner_dist = 10
     pwt_outer_dist = 20
 }


//-----------------------------------------------
Behavior = BHV_OpRegionRecover
{
  name         = recover
  pwt          = 300
  updates      = RECOVER_UPDATES
  activeflag   = RECOVER = true
  inactiveflag = RECOVER = false

            polygon = pts={-85,-48 : 59,21 : 90.9,-52.4 : -53.1, -121.4}
                      trigger_entry_time = 1
                      trigger_exit_time  = 1
}
```


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Aquaticus Helm Hierarchy Tree

uHelmScope

```
Mode-Variable=MODE
ACTIVE
   RECOVERING
   RETURNING
   INGAME
      SOLOPLAY
         ATTACKING
            TAGGED
            UNTAGGED
               AVOIDING
         ATTACKING_LEFT
            TAGGED
            UNTAGGED
         ATTACKING_RIGHT
            TAGGED
            UNTAGGED
         DEFENDING
            PASSIVE
            PROTECTING
      TEAMPLAY
         TRAILING
         COVERING
         SHIELDING
         STATIONING
INACTIVE
```

meta_heron.bhv

```
//#############################################################################
Behavior = BHV_Waypoint
{
  name               = waypt_grab
  pwt                = 50
  perpetual          = true

  condition          = (MODE == UNTAGGED) and (MODE == ATTACKING)
  runflag            = BOT_DIALOG_STATUS=Attacking
  endflag            = FLAG_GRAB_REQUEST=vname=$(RNAME)
  endflag            = TAGGED=true

  speed              = 5 // meters per second
  capture_line       = false
  capture_radius     = 7.0
  slip_radius        = 5.0

  points             = $(GRAB_POS)
}

//#############################################################################
Behavior = BHV_Waypoint
{
  name               = left_waypt_grab
  pwt                = 50
  perpetual          = true
  updates            = UPDATE_WPT
  condition          = (MODE == UNTAGGED) and (MODE == ATTACKING_LEFT)
  runflag            = BOT_DIALOG_STATUS=Attacking
  endflag            = FLAG_GRAB_REQUEST=vname=$(RNAME)
  endflag            = TAGGED=true

  speed              = 5 // meters per second
  capture_line       = false
  capture_radius     = 7.0
  slip_radius        = 5.0

  points             = $(GRABL_POS):$(GRAB_POS)
  visual_hints = vertex_size=0, edge_size=0
  visual_hints = vertex_color=invisible, edge_color=invisible
  visual_hints = nextpt_color=invisible, nextpt_lcolor=invisible
}
```


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Aquaticus Helm Hierarchy Tree

meta_heron.bhv

uHelmScope

- Mode-Variable=MODE
- ACTIVE
  - RECOVERING
  - RETURNING
  - INGAME
    - SOLOPLAY
      - ATTACKING
        - TAGGED
        - UNTAGGED
          - AVOIDING
      - ATTACKING_LEFT
        - TAGGED
        - UNTAGGED
      - ATTACKING_RIGHT
        - TAGGED
        - UNTAGGED
      - DEFENDING
        - PASSIVE
        - PROTECTING
    - TEAMPLAY
      - TRAILING
      - COVERING
      - SHIELDING
      - STATIONING
- INACTIVE

```
//#############################################################################
Behavior = BHV_Trail
{
  name                = trail_mokai
  pwt                 = 100
  condition           = MODE == TRAILING
  runflag             = BOT_DIALOG_STATUS=Trailing
  contact             = $(VTEAM)_one
  decay               = 15,30
  extrapolate         = false
  on_no_contact_ok    = true
  time_on_leg         = 60

  nm_radius           = 1
  no_alert_request    = false
  post_trail_dist_on_idle = true
  pwt_outer_dist      = 1000
  radius              = 2
  trail_angle         = 180
  trail_angle_type    = relative
  trail_range         = 15

  updates             = TRAIL_UPDATES
}
```


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MOOS-IvP & Aquaticus Integration

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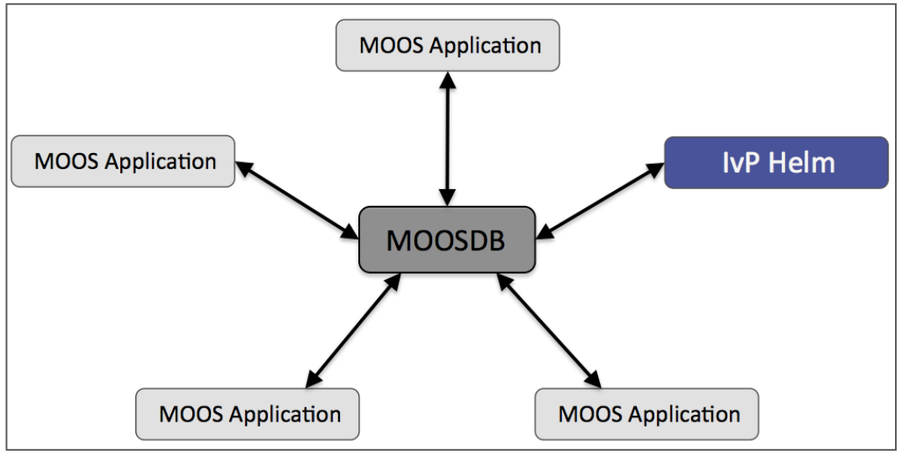
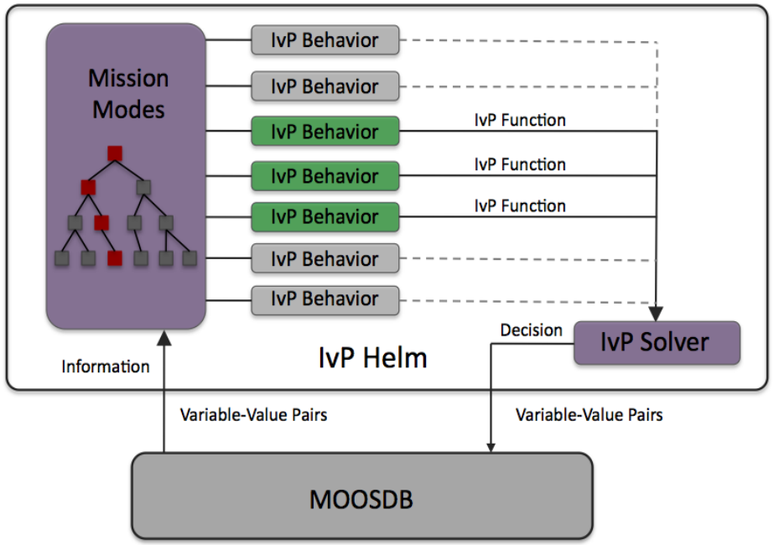
Supported Ways to Integrate with MOOS-IvP

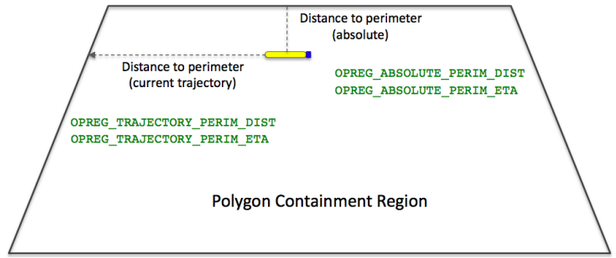


On-water Safety/Interventions



Benefits:

- Leverage IvP Helm
- Safety!!!!!!!
- Mission-planning tools
- Mission execution tools
- Post-mission analysis/debugging



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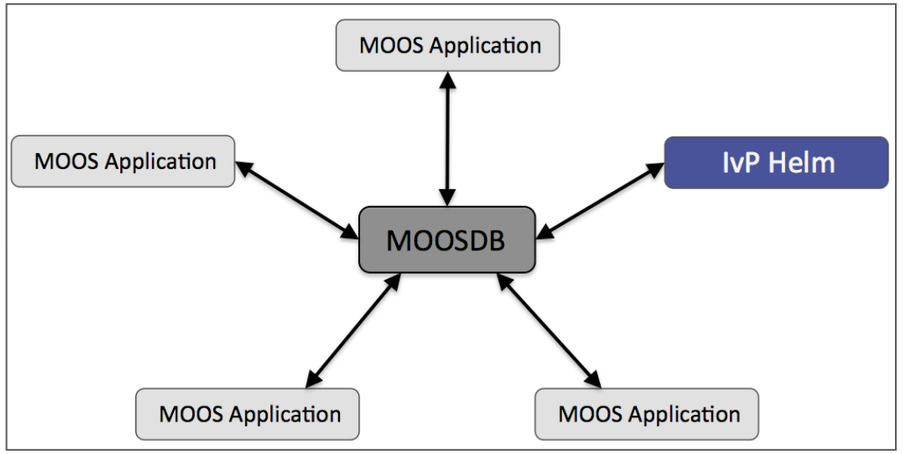
Supported Ways to Integrate with MOOS-IvP



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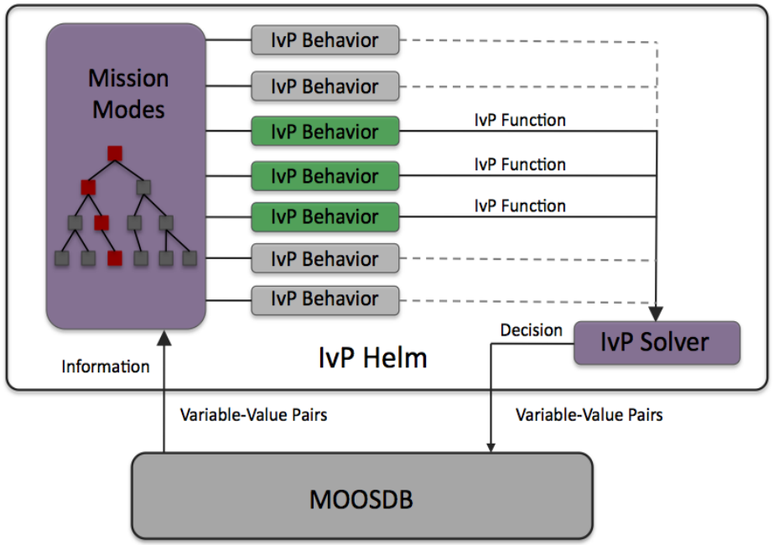

Methods:

1. pHelm-IvP directly – using Modes and Behaviors

Benefits:

- Leverage IvP Helm
- Safety!!!!!!!
- Mission-planning tools
- Mission execution tools
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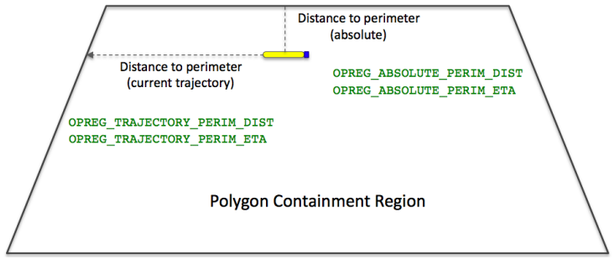

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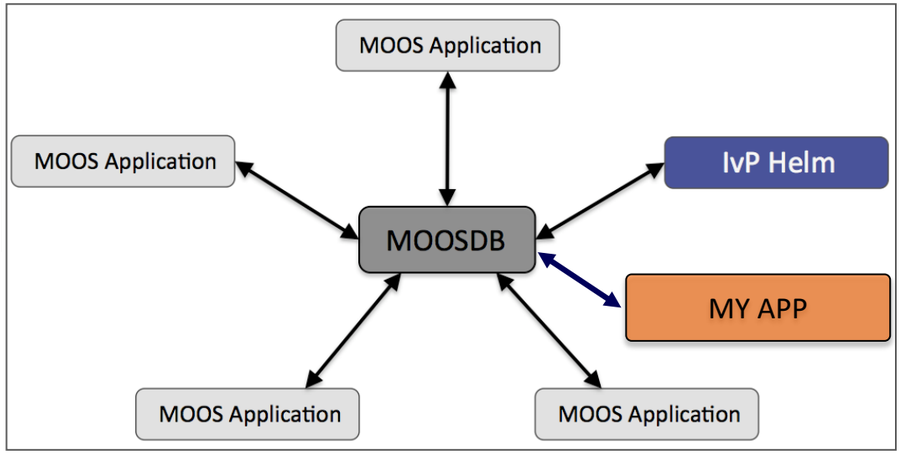
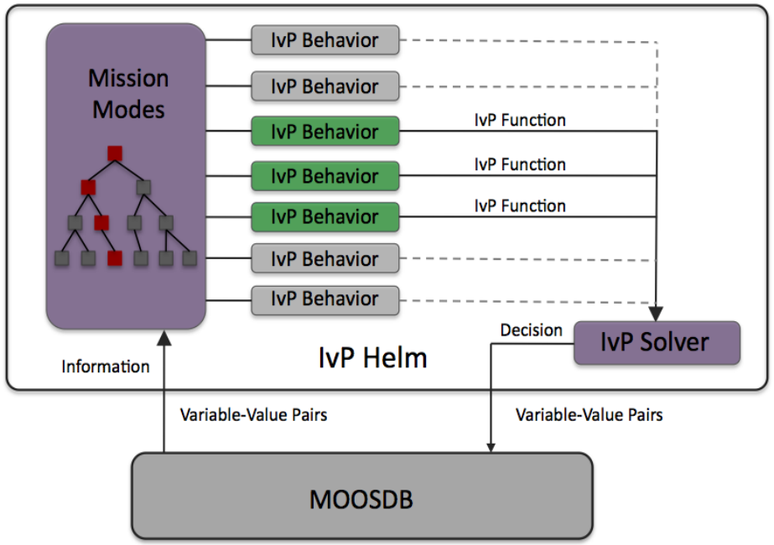
Supported Ways to Integrate with MOOS-IvP



On-water Safety/Interventions

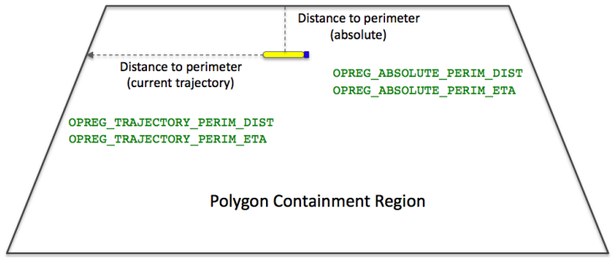


Methods:

1. pHelm-IvP directly – using Modes and Behaviors
2. Create MOOS Applications – poke pHelm-IvP
   a) Change modes
   b) Change behavior parameters

Benefits:

- Leverage IvP Helm
- Safety!!!!!!!
- Mission-planning tools
- Mission execution tools
- Post-mission analysis/debugging



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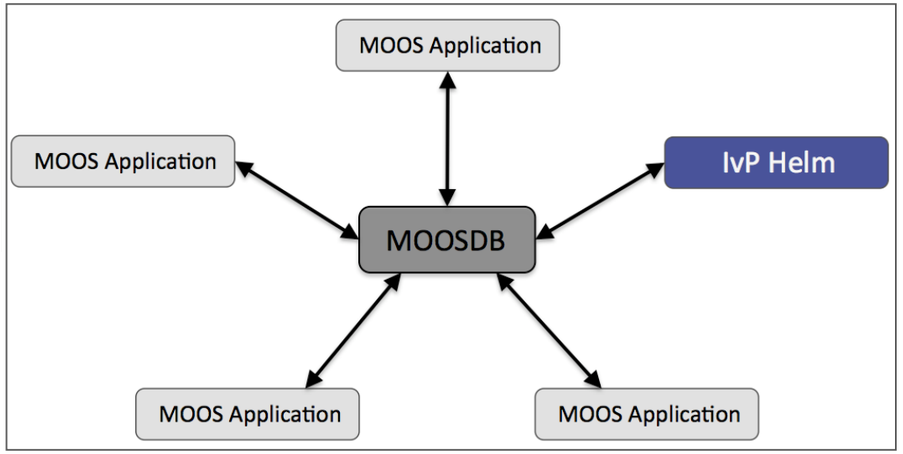
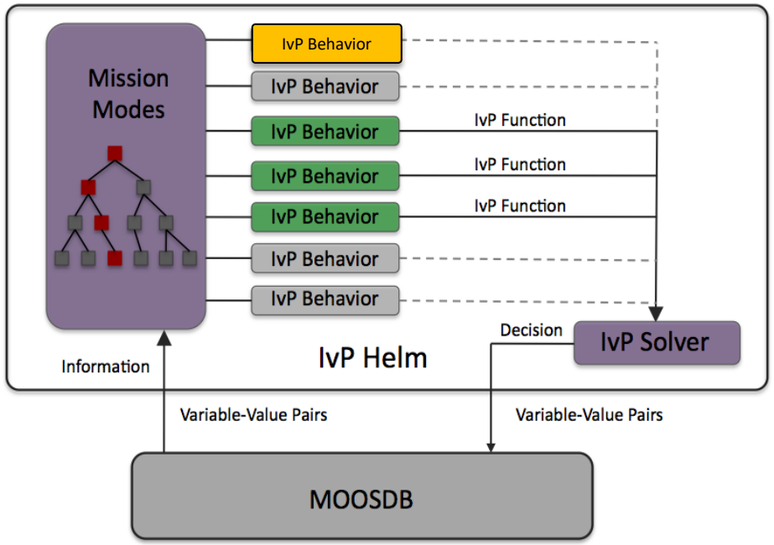
Supported Ways to Integrate with MOOS-IvP



On-water Safety/Interventions



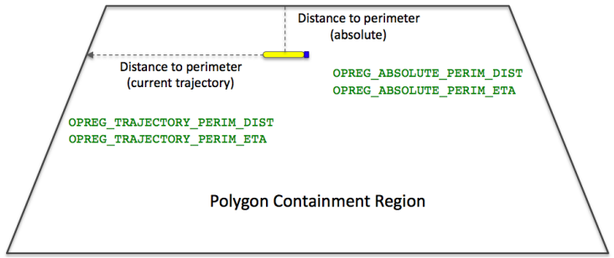
Methods:

1. pHelm-IvP directly – using Modes and Behaviors
2. Create MOOS Applications – poke pHelm-IvP
   a) Change modes
   b) Change behavior parameters
3. Create Behaviors (c++)*

*example using python in pLearn

Benefits:

- Leverage IvP Helm
- Safety!!!!!!!
- Mission-planning tools
- Mission execution tools
- Post-mission analysis/debugging



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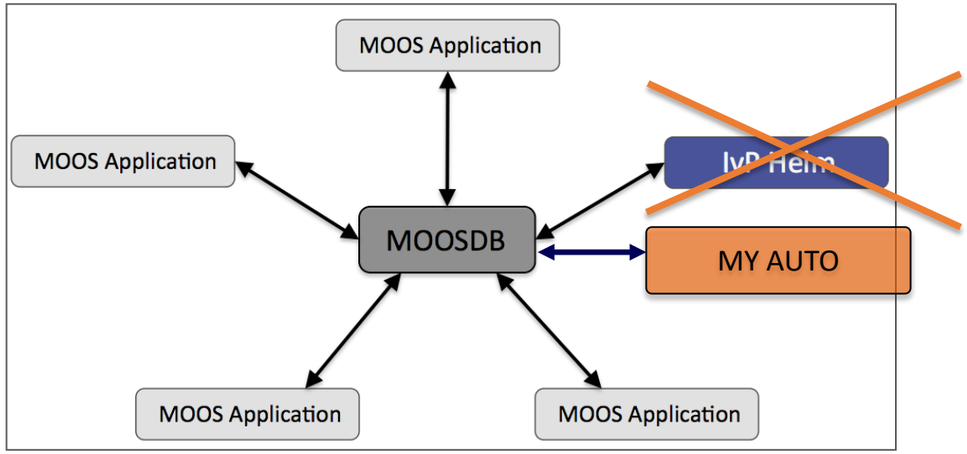
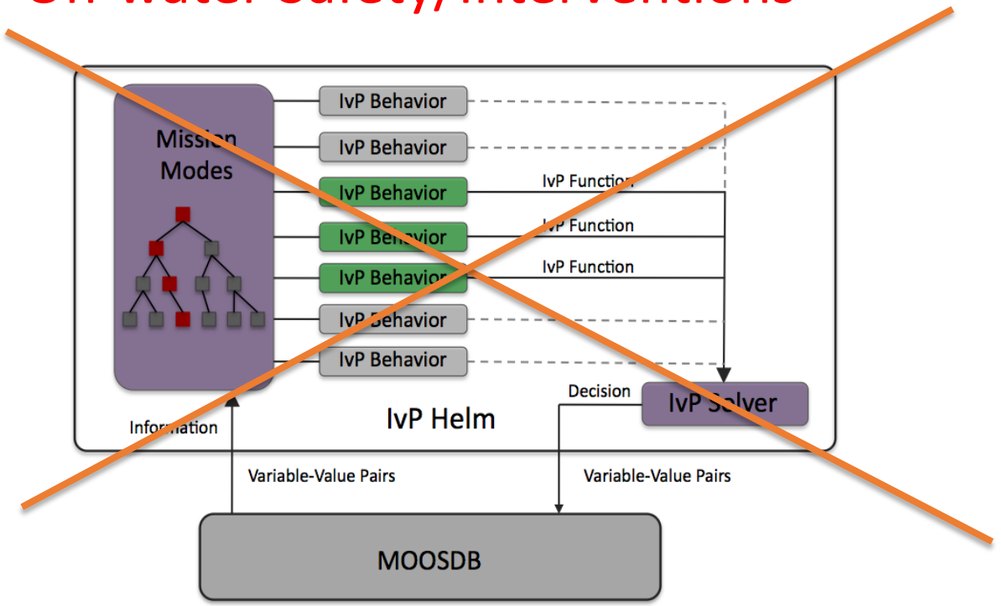
Unsupported Ways to Integrate with MOOS



On-water Safety/Interventions

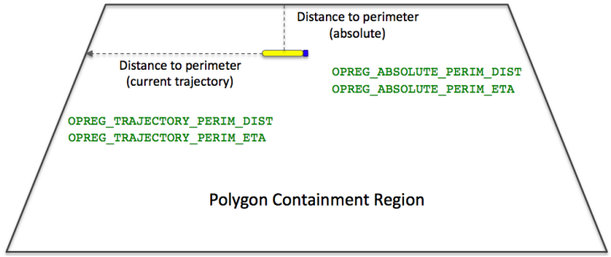


Methods:

Bypass pHelm-IvP – directly publish to DESIRED_HEADING and DESIRED_SPEED

Disadvantages:

- Leverage IvP Helm
- Safety!!!!!!!
- Mission-planning tools
- Mission execution tools
- Post-mission analysis/debugging



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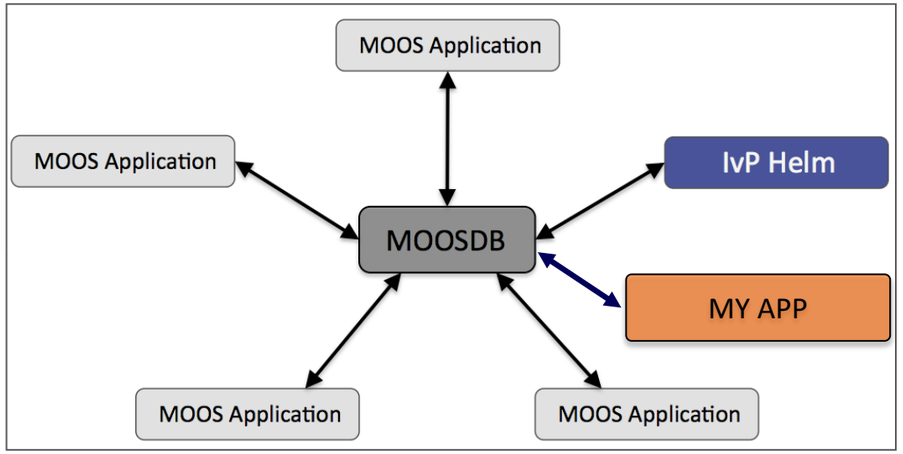
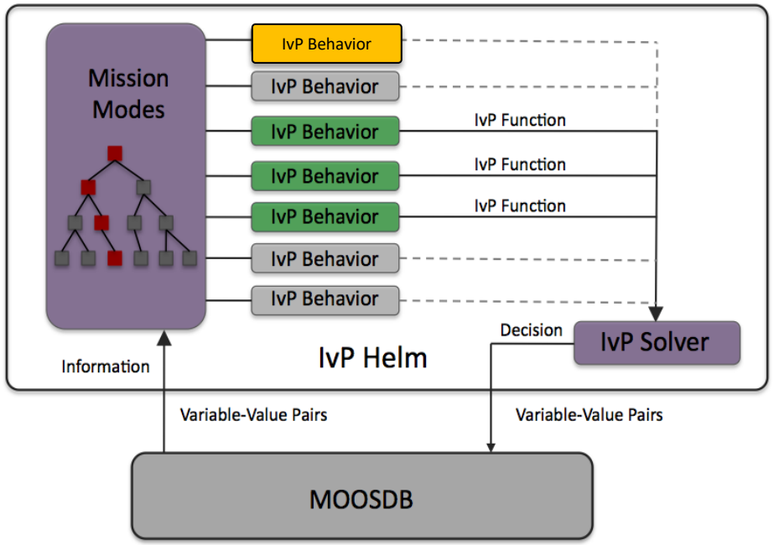
Unsupported Integrate Other Middlewares with MOOS-IvP

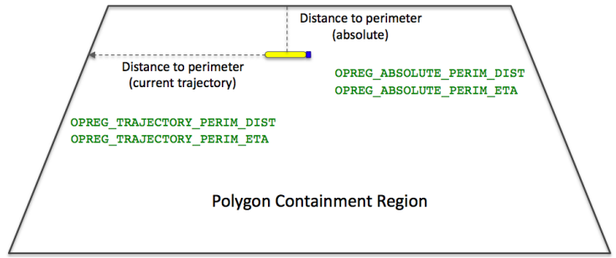


On-water Safety/Interventions



Benefits:

- Leverage IvP Helm
- Safety!!!!!!!
- Mission-planning tools
- Mission execution tools
- Post-mission analysis/debugging



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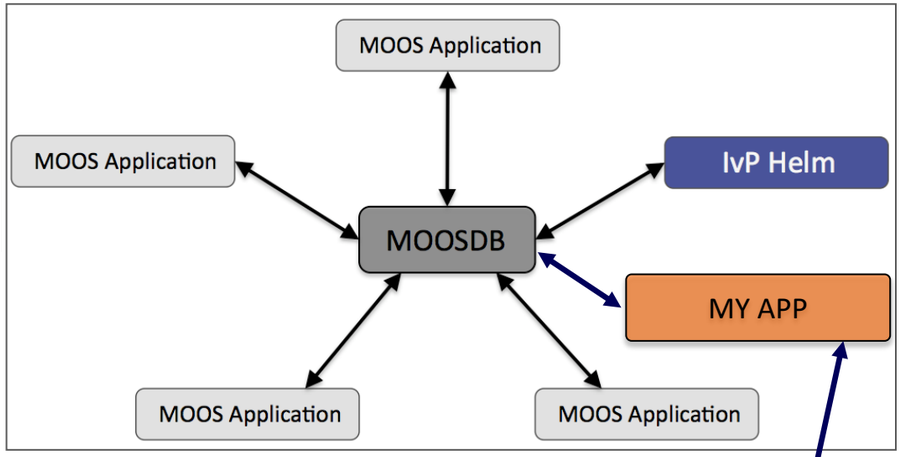
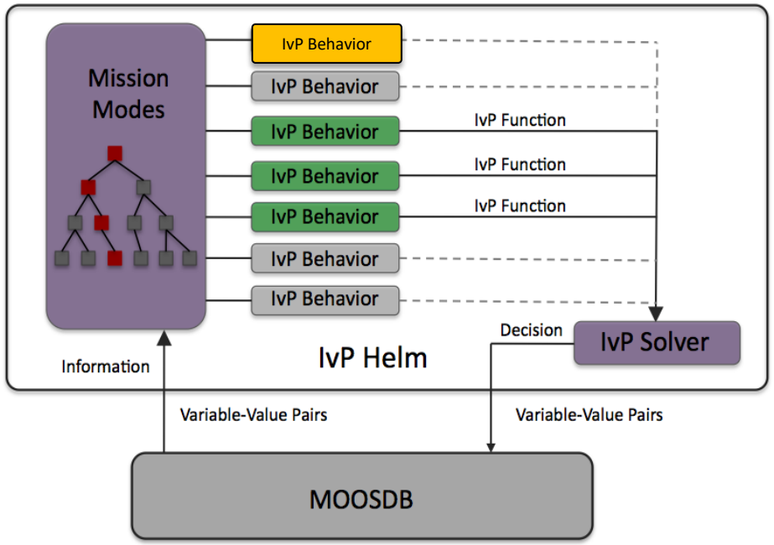
Unsupported Integrate Other Middlewares with MOOS-IvP

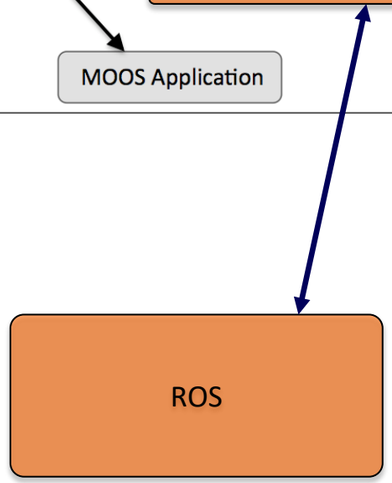


On-water Safety/Interventions



Methods:

1. ROS/MOOS Bridge
2. LCM/MOOS Bridge
3. NMEA Strings through Sockets



Benefits:

- Leverage IvP Helm
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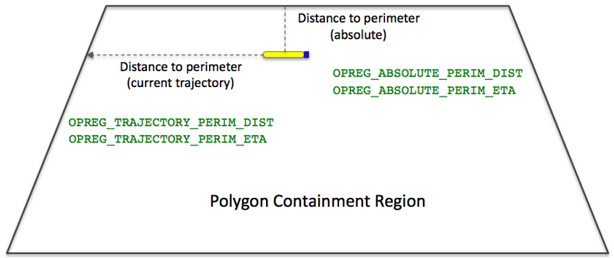

*example using python in pLearn

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MOOS-IvP & Aquaticus Analysis Tools

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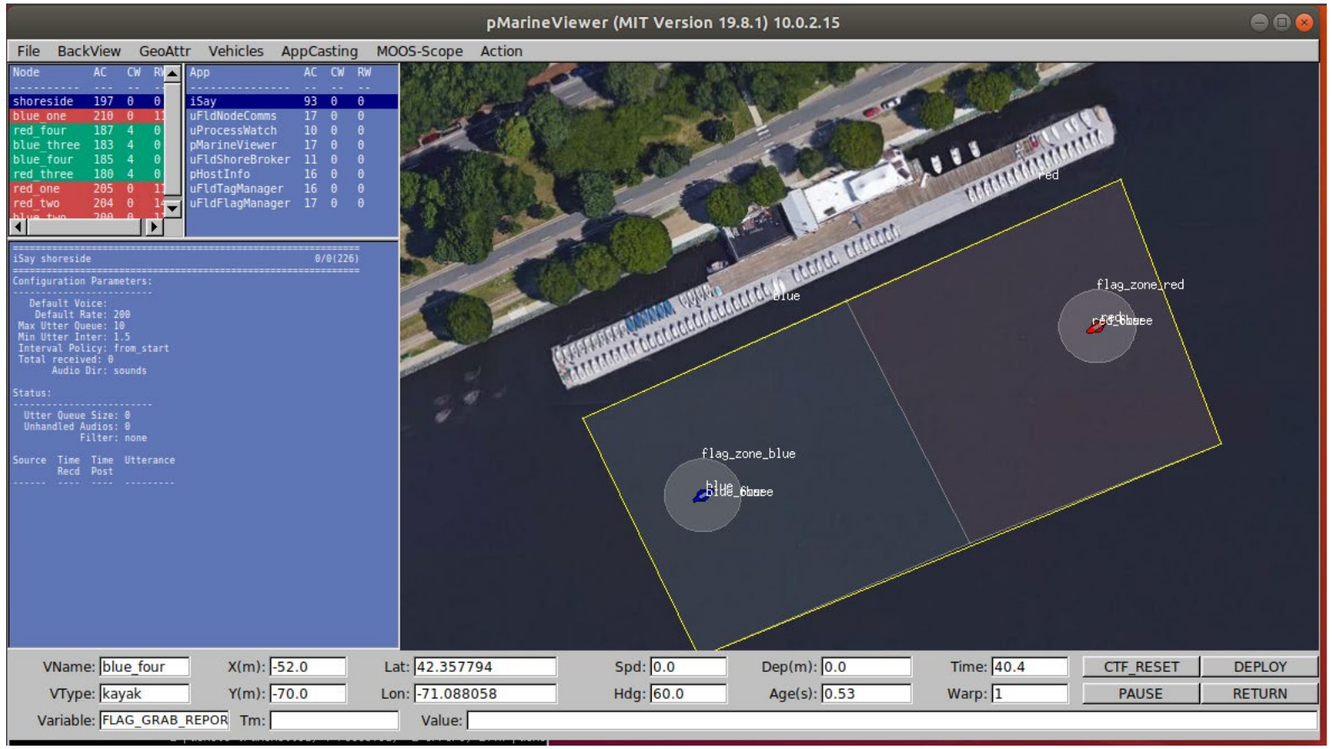
IvP Mission Tools

pMarineViewer

- AppCasting
- ‘SPACE’ command window



uHelmScope

- ‘h’

```
Mode-Variable=MODE
ACTIVE
   RECOVERING
   RETURNING
   INGAME
      SOLOPLAY
         ATTACKING
            TAGGED
            UNTAGGED
               AVOIDING
DEFENDING
            PASSIVE
            PROTECTING
      TEAMPLAY
         TRAILING
         COVERING
         SHIELDING
         STATIONING
INACTIVE
```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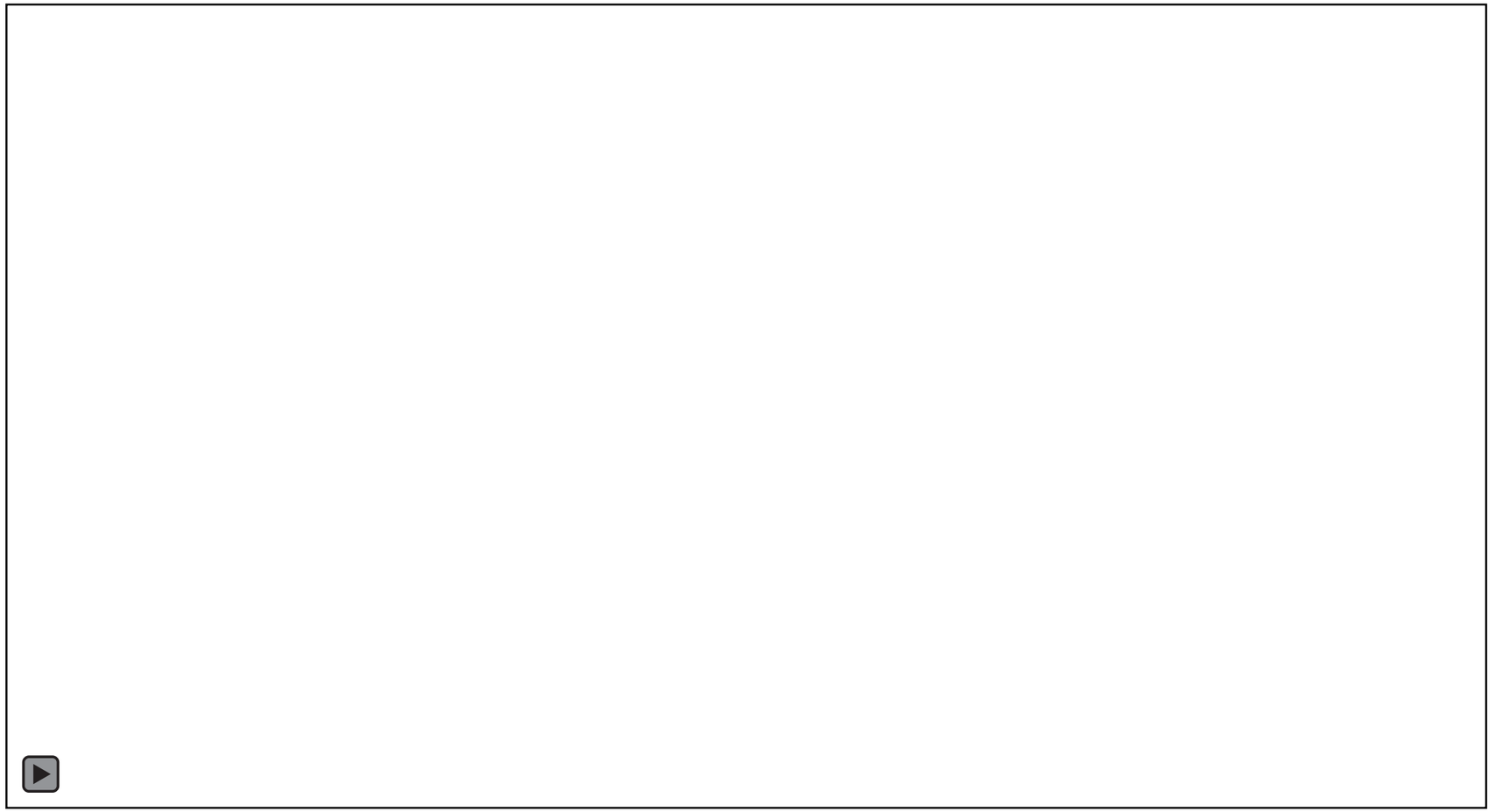
IvP Post Mission Tools

- Alogview – all vehicles



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IvP Post Mission Tools

aloggrep: command line tool

```
$ aloggrep alpha.alog NAV_*
$ aloggrep alpha.alog NAV_* >  nav.txt
$ aloggrep alpha.alog NAV_* >  nav.txt
```

General message (local) vs sent to others

AQUATICUS_GAME
AQUATICUS_GAME_ALL
AQUATICUS_GAME_BLUE_TWO

https://oceanai.mit.edu/ivpman/pmwiki/pmwiki.php?n=Tools.AlogIntro

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IvP Post Mission Tools

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IvP Post Mission Tools

aloggrep: command line tool

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```

General message (local) vs sent to others

AQUATICUS_GAME
AQUATICUS_GAME_ALL
AQUATICUS_GAME_BLUE_TWO

Useful Aquaticus Variables

NAV_*

AQUATICUS_GAME
SAY_MOOS*

BLUE_SCORE
RED_SCORE

FLAG_GRAB_REPORT
FLAG_GRAB_REQUEST
FLAG_RESET
FLAG_SUMMARY
HAS_FLAG_*
LED_HAVE_FLAG_SYSTEM
LED_IN_FLAG_ZONE_*
RED_FLAG_GRABBED
BLUE_FLAG_GRABBED

TAGGED_*
TAG_RELEASE_*
TAG_REQUEST
TAG_RESULT_*
TAG_RESULT_VERBOSE
UNTAG_REQUEST
ONFIELD_*

https://oceanai.mit.edu/ivpman/pmwiki/pmwiki.php?n=Tools.AlogIntro

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Lab 4.5: Preview

Goals:

- Run Project Aquaticus all autonomy simulation
- Explore pMarineViewer
- Review post-mission analysis tools

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